Dynamics of Boundary Currents and Marginal Seas: Windward Passage Experiment

William E. Johns
University of Miami
RSMAS/MPO
4600 Rickenbacker Causeway
Miami, Florida 33149-1098
Phone: (305)421-4054 Fax: (305)421-4696 email:: wjohns@rsmas.miami.edu

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LONG TERM GOALS

The long-term goals of this research are to understand the dynamics of ocean circulation near continental margins, with emphasis on western boundary current systems and circulation and exchange processes in marginal seas.

OBJECTIVES

From October 2003 to February 2005 a field experiment was conducted in the Windward Passage to determine the mean flow structure in the passage and its variability on time scales from tidal to seasonal. The data from this experiment will be combined with other recent time series measurements in the Caribbean Sea and Gulf of Mexico and available modeling results to address the dynamical linkages within the basins and implications for such processes as Loop Current eddy shedding in the Gulf of Mexico. Our objectives are to produce: (i) a detailed description of the mean inflow structure in the Windward Passage and its vertical and horizontal structure, (ii) a description of the modes of variability of the flow in the passage and their characteristic time scales and relationships to forcing, and (iii) an understanding of the relationship of the Windward Passage inflow to the other principal inflows and outflows from the basin.

APPROACH

Measurements collected in the program consisted of moored time series observations of currents using profiling (ADCP) and conventional current meters, and shipboard hydrographic and direct velocity profiling in the area surrounding the Windward Passage. Additionally, several high-resolution ocean circulation models for the region are being evaluated as part of the project, including HYCOM and the NRL Intra-Americas Sea Nowcast/Forecast System (IASNFS).

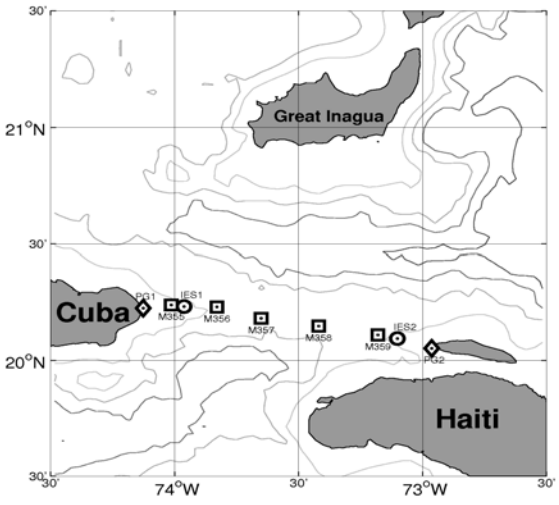

Figure 1. The Windward Passage moored array. Locations of current meter moorings (squares), tide gauges (diamonds), and inverted echo sounders (circle) are indicated.

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WORK COMPLETED

1. In February 2005 we successfully recovered a 5-mooring current-meter/ADCP array from the Windward Passage, providing a 17-month record of the flow variability in the passage (Figures 1 and 2). Shallow tide gauges and inverted echo sounders (IES's) deployed on each side of the passage were also successfully recovered. Data recovery from the current meters was good, with 16 of 18 instruments returning full records. Data recovery from the ADCPs was disappointing, with only two of the ADCPS returning useful data records. Both tide gauges returned complete and high-quality records, while one IES returned a good data record. Processing of all the time series records is complete and scientific analysis of the data is in an advanced stage.

2. Four hydrographic (CTD/LADCP) and shipboard ADCP surveys were conducted in the Windward Passage and surrounding region, in October 2003, April 2004, October 2004, and February 2005, aboard the R/V's Seward Johnson and NOAA Ronald Brown. The observations include the area of Windward Passage and the areas upstream of Windward Passage in the main passages through the southern Bahamas, and the area south of Cuba in the western Cayman Basin. Processing of the CTD and LADCP data is complete including CTD calibration and estimation of transports from the LADCP data for all sections.

RESULTS

1. The transport entering Windward Passage is highly variable, including reversals to net outflow. The most intense flows are located on the western side of the passage, where a strong inflowing jet is typically found against the eastern shore of Cuba (Fig. 2). The transport through the passage tends to follow the intensity of this feature. Transports measured during the cruises ranged from –0.3 Sv (outflow) to 9.4 Sv (inflow), with an average inflow of 3.8 Sv. Corresponding transports derived from the current meter array range from approximately –5 to 15 Sv, with an average inflow of 3.6 Sv (Fig. 3). The standard error of the mean transport for the 17-month period of the array is ±1.7 Sv based on the observed transport variance and the mean decorrelation time scale.

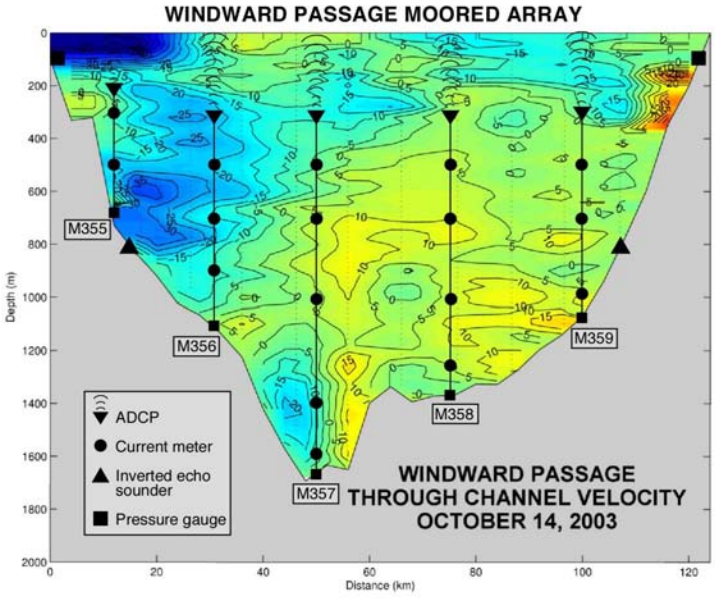

Figure 2. The Windward Passage moored current meter array, in cross-section view, superimposed on the velocity structure in the passage observed during the October 2003 cruise. Blue shades represent inflow to the Caribbean.

Unfortunately a planned extension of the transport time series to 3 years to obtain a more robust mean transport value and to examine interannual variability was not possible due to funding constraints. A preliminary comparison of the observed transport time series with the predicted transport from the NRL IASNFS

system during the period of the moored array shows excellent agreement in terms of variability but with a smaller mean transport than the model by about 2 Sv.

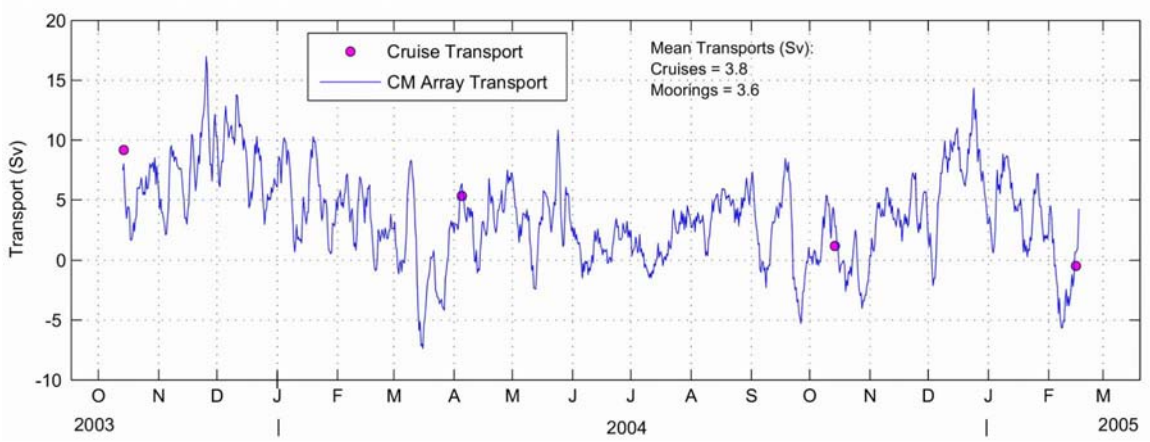

Figure 3. Transport time series for the net flow through Windward Passage derived from the moored current meter array, with the LADCP-derived cruise transports superimposed. Positive transports represent flow into the Caribbean.

2. The vertical structure of the flow through the passage tends to be quite robust and less variable than the transport itself, with typically a net inflow found above ~600 m, a net outflow between ~700-1200 m, and a deep inflow near the bottom (Fig. 4). Thus, on average, surface and thermocline waters are entering the Caribbean Sea via Windward Passage, intermediate waters are being exported, and deep water are entering. The deep flow is more clearly evident in the moored time series data (Fig. 5) where a persistent inflow with speeds of 20-40 cm/s is typically observed (which by chance happened to be weak or even reversed during two of the four cruises). This deep inflow continues into the Cayman basin as a slope-following jet at about 2000 m along the south coast of Cuba. These are the first direct measurements of this deep inflow, which represents one of two pathways by which deep waters of the Caribbean and Gulf can be ventilated from the Atlantic (the other being the Anegada/Jungfern passage south of Puerto Rico). Preliminary estimates of the mean deep inflow suggest a value near 0.5

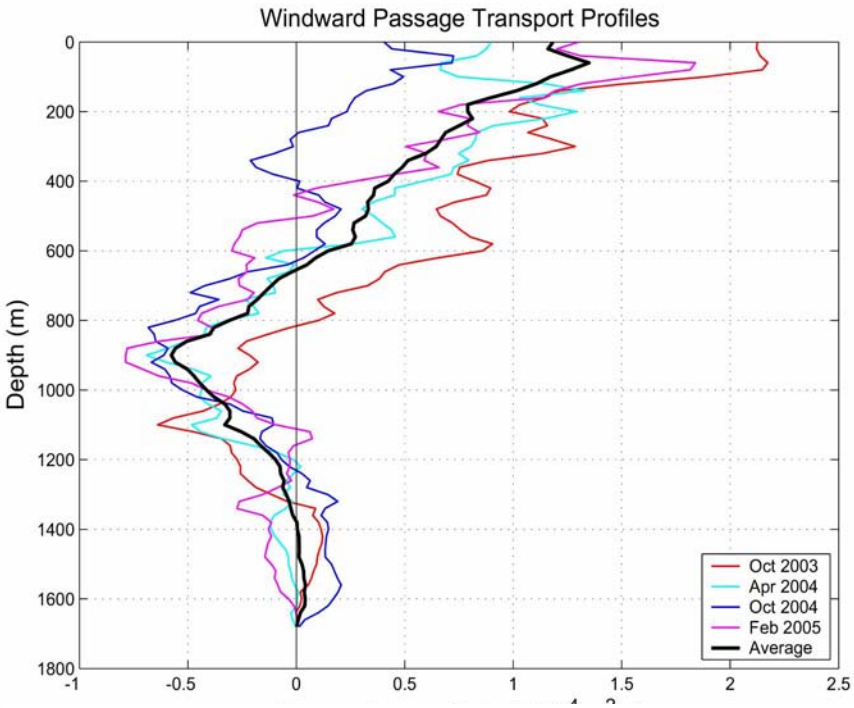

Figure 4. Transport profiles in the Windward Passage for each of the four project cruises, derived from lowered-ADCP sections. The average inflow/outflow profile is indicated by the black line.

Sv, which is about twice the corresponding value for the Anegada/Junfern inflow and indicates that Windward Passage in fact may be the dominant deep water source for the Caribbean.

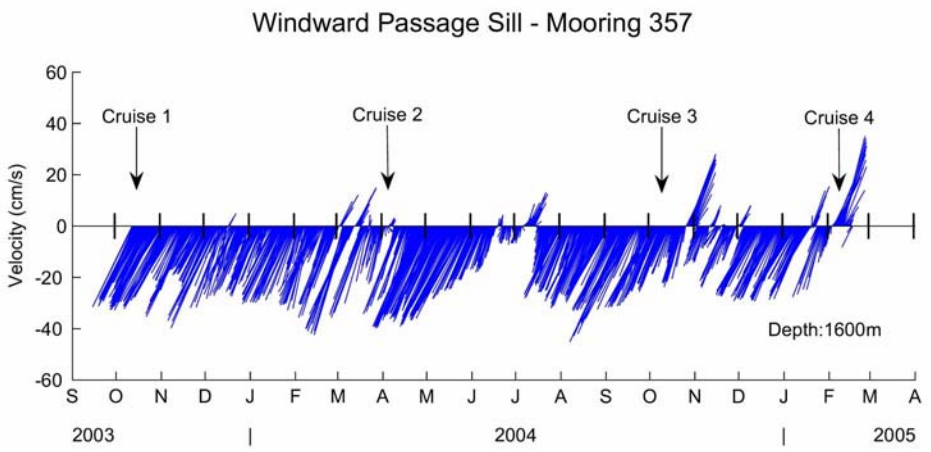

Figure 5. Current vector time series from the 1600 m current meter located just above the Windward Passage sill (1670 m, see Figure 2). Speeds associated with the deep overflow reach 40 cm/s, with intermittent reversals.

3. The source of the deep inflow through Windward passage is derived from a branch of the Deep Western Boundary Current (DWBC) that splits off the main path of the DWBC outside the Bahamas and filters through deep passages in the central Bahamas, a new discovery made in this program. Repeated sections made across the deep passages in the southern Bahamas (Fig. 6) show that almost half of the total Deep Western Boundary Current, and nearly all of the upper DWBC (which is associated with waters formed in the Labrador Sea), is diverted through these passages to form a strong deep jet of 5-7 Sv flowing southeastward along the coasts of Cuba and Hispaniola *inside* the Bahamas island arc. The possible impact of this diversion of the DWBC and mixing in the Bahamian passages on the structure and dynamics of the DWBC as it reenters the Atlantic north of Puerto Rico is being investigated.

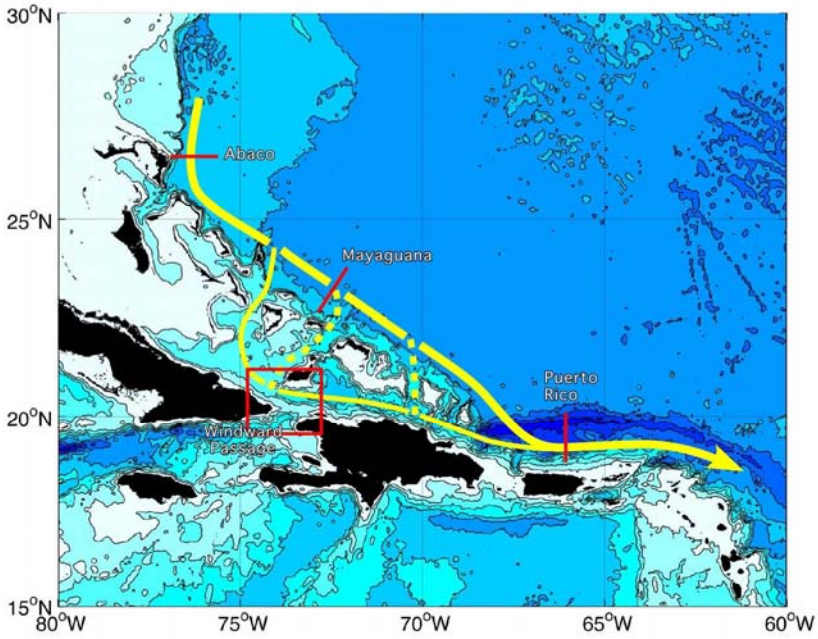

Figure 6. Schematic of the bifurcation of the Atlantic Deep Western Boundary Current (DWBC) through the southern Bahamas. The main channels through which the outer DWBC bleeds into an "inner" DWBC in the deep passage north of Cuba and Hispaniola are indicated. The "inner" and outer DWBC paths rejoin again north of Puerto Rico.

In addition to the active ongoing analysis of the Windward Passage Experiment we are wrapping up research efforts on three other projects: (1) the 2002 Aegean Sea Drifter program, which revealed new features of the circulation and eddy field in the Aegean Sea (article in press, Olson et al., 2006), (2) the summer circulation of the Red Sea from an opportunistic 2001 survey aboard the R/V Maurice Ewing (manuscript submitted, Sofianos and Johns, 2006), and (3) the 1997-1998 Straits of Hormuz Experiment, where follow-up modeling studies conducted by Ph.D. student F. Yao (in two manuscripts to be submitted this year) have revealed new aspects of the hypersaline water mass formation mechanisms in the Gulf and the forced exchange between the Gulf and the Indian Ocean.

IMPACT/APPLICATIONS

The results emerging from the Windward Passage Experiment represent exciting new findings in a region that has been virtually unexplored to date. In addition to the scientific results from the program, the measurements will be highly valuable to marine search-and-rescue and interdiction activities in the Cuba-Haiti region. Data will be shared with modeling groups, and the capability of existing high-resolution, real-time data assimilative ocean circulation models (e.g., HYCOM, IASNFS) to capture the flow variability in this region will be evaluated.

TRANSITIONS

None

RELATED PROJECTS

The Windward Passage program has strong linkages to current modeling efforts in the Caribbean and Gulf regions. The HYCOM Consortium, involving investigators from RSMAS and NRL and funded by NOPP, (lead PI: E. Chassignet) is currently performing a set of high-resolution data assimilation experiments for the North Atlantic that include the area of the Caribbean Sea and Gulf of Mexico. A similar effort is currently ongoing at NRL using a z-level model (the IASNFS model by Preller/Ko). These simulations will provide model-based analysis products for the IAS region that will allow detailed comparisons with our observations and with other regional observations including Mexican current meter arrays deployed off Yucatan and IFM-GEOMAR inflow measurements in the eastern Caribbean.

REFERENCES

PUBLICATIONS

Olson, D. B., V. H. Kourafalou, W. E. Johns, G. Samuels, and M. Veneziani (2006): Aegean surface circulation from a satellite-tracked drifter array. *J. Phys. Oceanogr.* (in press).

Sofianos, S. and W. E. Johns (2006): Observations of the summer circulation of the Red Sea, *J. Geophys. Res.* (submitted).

PATENTS None.

HONORS/AWARDS/PRIZES None.